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Pressure relief technique to achieve endotracheal tube cuff pressures within the recommended range

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Pressure relief technique to achieve endotracheal tube cuff pressures within the recommended range.

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A research report submitted to the Faculty of Health Sciences, University of the Witwatersrand, Johannesburg in partial fulfilment of the requirements for the degree of Master of Medicine in the branch of Anaesthesiology.

Johannesburg, 2020

Declaration

I, Tracey Jade Ferreira declare that this research report is my own unaided work. It is being submitted for the Degree of Master of Medicine in the branch of Anaesthesiology at the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination at any other University.



20 October 2020

Abstract

Study Objective

The complications of both high and low endotracheal tube (ETT) cuff pressure have been well documented. A number of ETT cuff pressure estimation techniques have been employed by practitioners in the absence of a manometer, particularly in resource-limited settings. These techniques have largely been shown to be unreliable. The pressure relief technique (PRT) has been described, with variations in the exact method. This study aims to determine if PRT can achieve ETT cuff pressures within the recommended range.

Design

A cross-sectional study was performed.

Setting

The study took place in the theatre complex of Chris Hani Baragwanath Academic Hospital in Johannesburg, South Africa.

Patients

Included in the study were 146 adult surgical patients undergoing general anaesthesia.

Interventions

The PRT, using a predetermined, standardised volume of air, was performed by over-inflating the ETT cuff and then allowing the plunger of the syringe to recoil until it stopped moving.

Measurements

ETT cuff pressure was measured with a manometer and recorded. The volume of air remaining in the ETT cuff was calculated and recorded.

Main Result

A statistically significant number, 93 (63.7%), of ETT cuff pressures fell within the recommended range. A minimum ETT cuff pressure of 12 cmH_2O and a maximum of 42 cmH2O was recorded. ETT brand had a significant impact on ETT cuff pressure ($p=0.001$). The volume of air remaining in the ETT cuff, after the PRT was performed, was significantly impacted by the brand ($p<0.0005$) and size ($p<0.0005$) of ETT.

Conclusions

While the manometer remains the gold standard in ensuring ETT cuff pressures within the recommended range, in the absence of a manometer, the PRT yields a statistically significant number of ETT cuff pressures within the recommended range.

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Abbreviations

BD	Becton Dickinson
BMI	Body mass index
CHBAH	Chris Hani Baragwanath Academic Hospital
ETT	Endotracheal tube
ICU	Intensive care unit
MLT	Minimum leak technique
MOV	Minimal occlusive volume technique
PBP	Pilot balloon palpation
PRT	Pressure relief technique
USA	United States of America

Statement

The Research Report consists of a literature review, draft article, study proposal and appendices. The study proposal is included for background reference and is not for examination.

The formatting of this Research Report complies with the University of the Witwatersrand's Style Guide for Theses, Dissertations and Research Reports. The formatting of the draft article may differ from the author guidelines of the Journal of Clinical Anaesthesia, the journal to which it is intended to be submitted, in order to comply with the university's style guide.

Section 1: Review of the literature

1.1 Introduction

This literature review will give a brief history of endotracheal (ETT) intubation and ETT cuffs. It will outline the anatomy and blood supply of the trachea and the pathophysiology of complications secondary to both low and high ETT cuff pressures. Factors affecting ETT cuff pressure and current methods of ETT cuff pressure estimation will be described, before introducing a novel technique of ETT cuff pressure estimation. Previous studies that have examined this novel technique will be discussed.

1.2 History of endotracheal intubation

Endotracheal intubation was first described in 1543 by Andreas Vesalius who blew air into the trachea of dogs with pneumothoraxes by means of a tube to rhythmically inflate the lungs (1, 2). In the eighteenth century, Joseph O'Dwyer passed metal "O'Dwyer tubes" into the trachea blindly to use as airways in diphtheria cases. Shortly after this ETTs were first used to administer anaesthesia by Sir William MacEwen, who administered chloroform for dental procedures and also used endotracheal intubation to prevent blood from soiling the lower airways. In the early nineteenth century, the demand for endotracheal intubation was increasing and Magill and Rowbotham developed a red rubber tube that was designed with the anatomy of the airway in mind. These tubes had no cuff to create a seal and therefore, gauze was packed on either side of the rubber tube in the subglottis (3).

The concept of an ETT cuff was first used in 1869 in tracheostomy tubes, where Trendelenburg attached a rubber bag to the tube, with a pipe leading from the bag to outside of the patient's mouth. The bag could be inflated via the pipe in order to create a seal between the trachea and the tube. Eisenmenger then used a similar design in an ETT. Unaware of Trendelenburg and Eisenmenger's descriptions of the use of an ETT cuff, Guedel and Walters introduced its use, allowing for positive pressure ventilation. In 1906 Green pioneered the idea of pilot balloons as a way of estimating the ETT cuff pressure (2, 3). At this time, polyvinyl chloride

ETT cuffs, which exerted high pressures, were in use. In response to the high incidence of tracheomalacia and stenosis in patients with prolonged intubation, Geffin and Pontoppidan (4) began stretching ETT cuffs with high volumes of air before intubating patients. The authors describe ETT cuff pressures of over 200 cmH_2O being used to provide an airtight seal. After stretching the ETT cuffs, they were able to achieve the same seal at pressures of 40 cmH_2O. This was the first description of what is known as high-volume, low-pressure ETT cuffs which became the standard ETT cuff in use. Today the adult ETT most commonly used consists of the following components: a tube commonly made of polyvinyl chloride, a Murphy eye to prevent obstruction to airflow if the distal end of the tube is against the carina and a cuff with an inflating tube, pilot balloon and valve. The inflating tube is the conduit between the ETT cuff and the pilot balloon. The pilot balloon gives a crude indication of the pressure in the ETT cuff and the valve prevents air from leaving the ETT cuff after it has been inflated. Low-pressure ETT cuffs are most commonly in use today (5).

1.3 Anatomy and blood supply of the trachea

The trachea connects the larynx to the main bronchi and is composed of 18 – 22 cartilaginous, c-shaped rings, with a membranous wall on the posterior aspect (6). Between each cartilaginous ring there is an intercartilaginous membrane. The upper and lower limits of the trachea are the lower edge of the cricoid cartilage and the carina, respectively (6). The correct placement of an ETT results in the ETT cuff being positioned in the upper part of the trachea (5).

The upper part of the trachea derives its blood supply from the tracheoesophageal branches of the inferior thyroid arteries. The branches divide inferiorly and superiorly along the lateral wall of the trachea and anastomose with the divisions from above and below, forming a lateral longitudinal anastomosis along the trachea. The vessels of the lateral anastomoses divide into anterior and posterior divisions which travel within the intercartilaginous membranes to anastomose with the divisions from the opposite side. Capillaries then traverse the tracheal wall to form the submucosal capillary plexus (6). Perfusion of the submucosa of the trachea is dependent on the perfusion pressure in the submucosal capillary

plexus. The tracheal capillary perfusion pressure in humans ranges from 30 – 44 cmH_2O (7).

1.4 Complications of elevated ETT cuff pressure and pathophysiology

Recommendations state that ETT cuff pressure should be maintained between 20 – 30 cmH_2O (8, 9). Clinically, the documented sequelae of a raised ETT cuff pressure include the following: sore throat, hoarse voice, blood-stained expectorant (10), oedema of the trachea, ulcers in the trachea, necrosis of the trachea, destruction of tracheal cartilage and subsequent tracheomalacia and in severe cases tracheal rupture and fistulae. Healing of any of these areas can result in tracheal and subglottic stenosis (7).

When the pressure applied to the tracheal wall by an inflated ETT cuff exceeds perfusion pressure, blood supply will be compromised (7). In a study that used endoscopy to assess mucosal perfusion at different ETT cuff pressures, it was shown that when a lateral wall pressure of 30 cmH_2O was exerted on the trachea, there was already evidence that mucosal blood flow was obstructed. At a pressure of 40 cmH_2O blood flow over the cartilaginous rings as well as the posterior aspect of the tracheal wall was compromised (9).

The result of compromised mucosal blood flow is ischaemia, mucosal sloughing and ulceration. Inflammatory cells begin to accumulate in the ischaemic tissue and bacterial infiltration can occur. Ultimately these changes at the tissue level can result in the breakdown of cartilage and soft tissue in the tracheal wall (7). Superficial damage can occur if the ETT cuff pressure is elevated for as little as 15 minutes (9). During the healing process, the inflammatory response results in granulation tissue forming, which then progresses to form collagen fibres which contribute to fibrous thickening of the area. If severe enough this eventually results in subglottic stenosis (11). If the destruction of the soft tissue and cartilage is allowed to progress, erosion into adjacent structures can occur, resulting in tracheoarterial and tracheoesophageal fistulae (7).

1.5 Complications of under-inflated ETT cuffs

While the complications of over-inflated ETT cuffs have been well described, under-inflated ETT cuffs, particularly in patients admitted to intensive care units (ICU), carry a risk of inadequate tidal volume delivery due to air leaking past the ETT cuff, alveolar derecruitment and aspiration pneumonia secondary to oropharyngeal secretions leaking past the ETT cuff. It has been shown that ETT cuff pressure below 20 cmH_2O is an independent risk factor for developing ventilator-associated pneumonia (8).

Despite ETT cuff pressure playing a role in preventing leakage past the ETT, it has been shown that high-volume, low-pressure ETT cuffs form folds along the ETT cuff, creating gaps between the ETT cuff and the tracheal wall. Studies have assessed fluid leakage past high-volume, low-pressure ETT cuffs at various intracuff pressures and in various brands and models of ETTs. These studies found that even at pressures of 30 cmH_2O, the maximum prescribed pressure, small volumes of fluid still leak past the inflated ETT cuff (12-14).

1.6 Factors affecting ETT cuff pressure

Several factors have been identified as affecting ETT cuff pressure, after inflation by the intubating doctor has taken place. High peak airway pressures have been shown to increase ETT cuff pressures (15). The use of nitrous oxide is known to increase ETT cuff pressures as it is more soluble than the air inside the ETT cuff. Enclosed spaces expand if the gas they are exposed to is more soluble than the gas within them (16). Nguyen et al, in 1999, (17) supported this theory by demonstrating that when an ETT cuff was filled with a mixture of air and nitrous oxide, the pressures did not increase as significantly as when only air was used to fill the ETT cuff. Body and head movements in ICU patients have been shown to be a risk factor for elevated ETT cuff pressures, as well as coughing and suctioning (18). Patients undergoing laparoscopic surgery have been assessed to determine if insufflation of the abdomen has any effect on the ETT cuff pressure. In 2014, Wu et al (19) found that after insufflation ETT cuff pressures increased by as much as 5 – 7 cmH_2O. A further increase was noted when patients were put in the head-down position to facilitate laparoscopic surgery. Patient positioning is

also known to have an impact on ETT cuff pressures in ICU patients. It has been shown that any position other than the “supine position with neutral head position” has an impact on ETT cuff pressure with head anteflexion causing the greatest increase in pressures (20). Motoyama et al, in 2014, (21) showed that with time, ETT cuffs deflate and therefore have a drop in pressure, although it is unclear if the reason for this is a gradual escape of air from the ETT cuff or if air is lost during the measurement of ETT cuff pressure. The ideal gas laws demonstrate the effect that temperature has on gas volume and pressure. Gay-Lussacs law states that at a constant volume, pressure is directly proportional to temperature,

$$\left(\frac{P1}{T1} = \frac{P2}{T2}\right)$$

therefore if temperature increases, the pressure will increase (22). It has been shown that if the temperature of the gas inside the ETT cuff changes, the ETT cuff pressure may also be affected. This has significance in hypothermic patients who are rewarmed after intubation (23). ETT size has been evaluated as a factor affecting ETT cuff pressure in a number of studies but has largely been found to have no impact when the correct size ETT is chosen for the patient (24-26).

1.7 Methods of ETT cuff pressure estimation

A systematic review including nine studies, seven of which were randomised control trials, found that when ETT cuff pressure measurement is performed objectively with a manometer, significantly lower pressures are achieved when compared with subjective estimation techniques (27)

A number of subjective techniques to estimate ETT cuff pressure are employed by doctors and nurses. Techniques commonly described include the following:

- minimal occlusive volume technique (MOV) involves injecting air into the ETT cuff until no leak can be heard during positive pressure ventilation
- minimum leak technique (MLT) entails air being injected into the ETT cuff while auscultating the trachea until only a small leak is heard
- predetermined volume technique involves a volume of air, chosen at random, being injected into the ETT cuff

- finger palpation technique, also known as pilot balloon palpation (PBP), is where the ETT cuff pressure is estimated by palpating the pilot balloon (28).

Studies have shown that estimation techniques are ineffective. Stewart et al (28), in the United States of America (USA), in 2003, showed that estimation techniques, including MLT, predetermined volume and PBP, yielded pressures greater than 40 cmH_2O in 60% of patients. A study done in the USA, in 2004 (26), involved 93 patients and nurse anaesthetists, anaesthetic residents and anaesthesiologists in three different hospitals. It was shown that when estimating ETT cuff pressure without a manometer, only 27% of patients had ETT cuff pressures within the recommended range. ETT cuff pressures were below the recommended range in 23% of patients, while 50% were above. A study performed in two Johannesburg hospitals, in 2015 (24), with a sample size of 96, showed that in 64.5% of cases the ETT cuff pressure was above the recommended limit of 30 cmH_2O and only 18.7% of patients had ETT cuff pressures within the recommended range. The technique used most commonly was MOV, followed by the predetermined volume technique and then PBP. The difference between the pressures obtained with the various techniques was statistically insignificant. A randomised trial done by Tsaousi et al, in Greece, in 2018 (29) compared MOV, MLT, PBP and a fourth method they call air return method. It found that PBP had the highest incidence of over-inflation. The MLT had no cases of over-inflation, however, the highest incidence of underinflation was found in this group. MOV only showed over-inflation in 2.9% of cases, however 55.8% showed underinflation. A 2019 study, done in Iran (30), showed when the MLT was performed a mean ETT cuff pressure of 33.72 cmH_2O was obtained and when a predetermined volume was used a mean ETT cuff pressure of 46.07 cmH_2O was obtained.

PBP has been shown to be a poor predictor of ETT cuff pressure (31, 32). In 1990 in Spain, Fernandez et al (33) inflated ETT cuffs to low, recommended and high pressures and had physicians and nurses, at various levels of experience, estimate which category the ETT cuff pressure would fall into. The study showed that regardless of the level of experience of the medical professional, the accuracy of determining the ETT cuff pressure was poor. A study done in South Africa in

2011, looking at 44 care providers in the field of emergency medicine including nurses, paramedics and physicians showed that PBP had very low sensitivity for assessing ETT cuff pressures. Most participants estimated an ETT cuff pressure to be too low when, in fact, it was within the recommended range, and when ETT cuff pressures were high, they were assessed as being normal. Once again, years of experience did not determine accuracy in determining ETT cuff pressure with PBP (34). Another study, done in Poland in 2018, showed that although the ETT cuff pressures measured lower as the level of experience of the medical professional increased, with PBP, the median value for the most experienced care providers was still above the recommended range (35).

1.8 The pressure relief technique as a method of ETT cuff pressure estimation

A novel method of ETT cuff pressure estimation has been described with variations in name and methodology, in a number of studies. This method has been called the pressure relief valve technique (36), the passive release technique (37-39), and the air return method (29). Some articles have not named the technique but describe a similar concept (40-42). It will be referred to as the pressure relief technique (PRT) in this review.

1.8.1 Physical principles of the pressure relief technique

The principle of PRT is when the ETT cuff is over-inflated, it causes tracheal distention which then exerts an “opposing force of resistance” (36) on the ETT cuff. When the pilot balloon valve is opened by attaching a syringe, this force is transmitted to the plunger of the syringe and pushes it backwards. Theoretically, “when the syringe plunger stops moving, the tracheal wall pressure is considered equal to the cuff pressure, thus maintaining it at safe levels” (36). This relies on the physics principle of air moving down a pressure gradient.

1.8.2 Variations of the pressure relief technique

The first documented use of this technique that could be found is a 1988 study, in USA, where Gravenstein and Burwick (43) noted that “when inflating tube cuffs … when the inflating syringe is left inserted in the inflating (pilot) valve of the cuff after

inflation, the plunger of the syringe partially recoils." In this study a tracheal model was used and a predetermined volume of air (5 ml if a 5 ml syringe was used and 6 ml if a larger syringe was used) was inserted into the ETT cuff. The baseline pressure was measured, the ETT cuff was then deflated and re-inflated with the same volume of air and the syringe was left attached. The pressure was then measured after one minute. The syringe sizes used were 5 ml, 6 ml, 10 ml and 12 ml and 20 of each size were tested. The results showed that when the syringe was left attached and allowed to recoil, ETT cuff pressures were significantly lower. The 5 ml syringe gave the highest pressures of all four sizes, with a range of 42 – 130 cmH_2O with the syringe attached, compared to 160 – 206 cmH_2O when the syringe was not left attached. The best results were obtained with the 6 ml syringe which gave pressures of 19 – 50 cmH_2O with the syringe attached compared to 180 – 250 cmH_2O when the syringe was not left attached. It was noted that no leaks were present during positive pressure ventilation with a test lung attached for all syringe sizes. Of note is that despite pressures being significantly lower after the intervention, they still remained above the recommended limit (43). This could be attributed to a tracheal model being used which would not have the same properties as the human trachea.

In 1990, in USA, Resnikoff and Katz (41) noted how the study by Gravenstein and Burwick (43) failed to achieve the recommended pressures and attributed it to the high resistance of the syringes. The authors attempted to overcome this problem by using an epidural syringe and adding weights to the plunger. First, using a tracheal model, the ETT cuff was randomly inflated to 47 – 135 cmH_2O. Ten standard 6 ml syringes and 10 epidural syringes were tested by attaching them to the pilot balloon valve and allowing the plunger to recoil. Weights were added to the plungers of the epidural syringes until a pressure of 20 cmH_2O was achieved. They found that appropriate pressures were achieved when a 10 g weight was attached to the plunger. The mean post-recoil pressure after using the 6 ml syringes was 62 cmH_20. To determine the reproducibility, one modified epidural syringe was used 50 times and it was found to have a mean post-recoil pressure of 19 cmH_2O. The modified epidural syringe was then tested on 20 patients. After the intubator had over inflated the ETT cuffs to various pressures, the investigators measured the baseline pressure and then attached the modified syringe and

allowed the plunger to recoil until it stopped. The pressures achieved post recoil ranged from 13.5 – 21.7 cmH_2O with no leaks noted on positive pressure ventilation. The resultant pressures were independent of the initial ETT cuff pressure (41).

In 2002, in Israel, Somri et al (42) attempted to prevent the gradual increase in ETT cuff pressure during anaesthesia with nitrous oxide. A 20 ml syringe was left attached to the pilot balloon valve after ETT cuff inflation, for the duration of anaesthesia. ETT cuff pressure was measured hourly and the investigators auscultated over the sternal notch to check for air leaks hourly. The results of the study were promising with all the ETT cuff pressures remaining stable for the duration of surgery at around 15 cmH_2O. It is also reported that there were no air leaks for the duration of surgery. The study concludes by suggesting this method as an inexpensive way of controlling ETT cuff pressure during anaesthesia with nitrous oxide, however, no comparison was made to the stability of the ETT cuff pressure without the syringe being left attached to the pilot balloon valve (42).

One variable that is not standardised in studies describing this method is the brand and size of syringe used. Mac Murdo and Buffington, in USA (44), in 2004, looked at variation between brands and sizes and claim that these are both important factors which do impact outcomes. A three-phase experiment was performed where the barrel of a 60 ml syringe was used to imitate a trachea and a size 7.0 ETT was used.

Phase 1

The ETT cuff was inflated with air, to 48 – 61 cmH_2O. With a pressure transducer attached to the ETT cuff, 70% nitrous oxide was passed into the simulated trachea and ETT cuff pressures were recorded for one hour. It was found that pressures increased approximately 1.4 cmH_2O every two minutes and on average, increased by 38 cmH_2O in an hour (44).

Phase 2

A three-way tap was attached to the pilot balloon along with a pressure transducer and a syringe which had been “warmed up” by pushing the plunger in and out

twice. In this phase, 20 ml Terumo syringes, as well as 20 ml and 60 ml Becton Dickinson (BD) syringes were used. A fixed volume of 20 ml of air was injected into the ETT cuff and the plunger was then allowed to recoil until it stopped. The pressure at which the plunger stopped moving was recorded and labelled the "stick pressure". The three-way tap set up was then left in place as the ETT cuff was once again exposed to 70% nitrous oxide. It was found that even when the syringe was left in place as a pressure relief system, pressures continued to increase during nitrous oxide exposure, on average by 35 cmH_2O over an hour. The results were similar for all three syringes tested (44). These results are in opposition to Somri et al's (42) findings. One possible reason for the syringe not adjusting for the increased pressure is that static friction has occurred in the syringe, which prevents the plunger from moving after a being stationary for a period of time. The plunger may therefore need to be "warmed up" at intervals as it was at the beginning of the experiment (44).

Phase 3

The "stick pressure" was determined in an identical manner to Phase 2. An additional three-way tap was then added to the system so that a second syringe could be included. The ETT cuff was excluded, so there was a continuous system connecting the two syringes and the manometer. The pressure in the syringe being tested was gradually increased by pushing air from the second syringe into the system until the test syringe plunger began moving back. The pressure at which this occurred was documented and called the "slip pressure". During this phase, the effect of temperature on stick pressures was also investigated by warming the syringes to 45° C and repeating the experiment. The syringes tested in this phase were 10 ml, 20 ml and 60 ml BD, 20 ml Terumo and 20 ml Monoject™. The findings showed great variability among sizes and brands. Slip pressures ranged from 64 cmH_20 (60 ml BD) to 190 cmH_2O (20 ml Terumo). Clinically, if a syringe required such high pressures in order for the plunger to begin recoiling, this method would not be feasible as it is unlikely that an anaesthetist would inflate the ETT cuff to such pressures initially. Stick pressures also varied, the 60 ml BD had the lowest at 31 cmH_2O and the 20 ml Monoject™ had the highest at 82 cmH_20 (mean values). Also of value to note is that when one

syringe was repeatedly used Terumo syringes showed consistency whereas BD syringes tended to get sticky with repeated use. The temperature did not appear to have an effect on the stick and slip pressures (44). The physical principles governing the behaviour of various syringes will be discussed in section 1.8. The limitations of this study include a tracheal model being used rather than patients and it appears that one ETT was used for the duration of the study. It is not certain whether the elastic properties of the ETT cuff would be altered after many inflations and deflations. It is also not known how the addition of three-way taps to the system affects the resistance and reliability of the method (44).

A study performed in Korea, in 2009 (37), on 88 patients, used the PRT with both 10 ml and 20 ml syringes and two different brands of ETT. A predetermined volume of air (determined by how much air is required to fill the ETT cuff) was injected and then the syringe allowed to recoil spontaneously. The resultant ETT cuff pressure was then measured. The resultant ETT cuff pressures are shown in table 1:

Table 1: Cuff pressures after PRT in two different ETT brands with both 10 ml and 20 ml syringes

	ETT cuff Pressures (cmH_2O)	
	Euromedical® ETT	**Portex® ETT**
10 ml syringe	25.6 – 30.4	24.7 – 28.0
20 ml syringe	12.5 – 15.5	15.9 – 19.3

The pressures differed significantly between 10 ml and 20 ml syringes, with lower pressures being recorded when the 20 ml syringes were used ($p<0.05$) (37). Important to note is that pressures achieved were largely below the maximum recommended ETT cuff pressure of 30 cmH_2O.

Cho et al, in Korea, in 2010, conducted a follow up study by comparing three groups of physicians: group A which inflated the ETT cuff using PBP, group B which used the PRT with a 10 ml syringe and group C which used the PRT with an epidural syringe. This study was done on mannikins. The optimal range of ETT cuff pressures defined in this study was 16 – 40 cmH_2O. Group A had a mean ETT cuff pressure of 78.2 cmH_2O and only 16.7% of ETT cuff pressures were within the recommended range. Group B had a mean ETT cuff pressure of 56.1 cmH_2O and 23.3% were in the recommended range. Group C had a mean ETT cuff pressure of 19.1 cmH_2O with 100% in the recommended range (38).

Park et al, in Korea, in 2010 (39) investigated the PRT using mannikins, with 29 nurses inflating ETT cuffs using both PBP and PRT. Ease of use as well as resultant ETT cuff pressures were compared. A 10 ml syringe was used. No statistically significant difference was found in the ease of use of the two methods. There was, however, a significant difference between the ETT cuff pressures obtained when using the PBP method and the PRT method. The average ETT cuff pressure achieved using the PBP method was 39.3 cmH_2O and only 13.8% of nurses inflated the ETT cuffs to the recommended pressure. In comparison, 65.5% of nurses inflated the ETT cuffs to recommended pressures using PRT with the average ETT cuff pressure being 24.2 cmH_2O(39).

In 2014, a study conducted in Brazil, by Annoni et al, (36) first looked at 10 ml and 20 ml syringes in a tracheal model and then 5 ml, 10 ml and 20 ml syringes were tested on 20 ICU patients. The technique used was to attach a three-way tap to the pilot balloon valve and a manometer and syringe. Air was pushed into the ETT cuff with the syringe, taking small pauses until the plunger began to recoil. Once the plunger stopped moving the ETT cuff pressure was measured. In the first phase of the study where the tracheal model was used, the ETT cuff pressures remained above the recommended limit after the PRT: 45.2-59.6 cmH_2O for the 10 ml syringe and 35-84 cmH_2O for the 20 ml syringe. The correlation coefficients indicate that there is no reproducibility between syringes of the same brand and size. When tested on the ICU patients, all three sizes of syringes gave pressures above the recommended limit: mean of 105 cmH_2O for 5 ml, 69 cmH_2O for 10 ml and 45 cmH_2O for 20 ml (36). As other studies (38, 44) using tracheal models

have shown, the technique is not reliable in these models which do not have the same properties as a human trachea. The patients in this study were not anaesthetised and therefore the many factors that affect ETT cuff pressure that have been discussed in section 1.5, such as patient movement, position and coughing, could have affected the results. It also appears that the method of inflating the ETT cuff would allow for much operator-dependent variability with no standardisation in pause time or amount of air instilled into the ETT cuff.

The study by Tsaousi et al (29) has already been mentioned in section 1.6 as they compared four methods of ETT cuff pressure estimation. The inadequacy of PBP, MOV and MLT found by this study has already been discussed. In the fourth group, that included 34 patients, the PRT was used (called the air return method in this study). The specific methods used in this study are not clearly outlined. It is known that the ETT cuff was over inflated and that air was allowed to return to the syringe. It appears that a 10 ml syringe was used, as this was the syringe used for ETT cuff inflation throughout the study. ETT cuff pressures were then measured. It was found that 70% of patients in the PRT group had ETT cuff pressures within the recommended limit. The rate of underinflation in this group was 29,4% and only one patient's ETT cuff was inflated above the recommended pressure limit. It was found that the rate of both under and over-inflation varied significantly between the four groups (29).

More recently, in 2017, in Uganda (40), a study investigated this method of ETT cuff pressure estimation using a 7 ml loss of resistance syringe. The sample included 178 patients who were randomised to either a PBP group or a loss of resistance group (for consistency this group will be referred to as the PRT group). In the PBP group, the anaesthetist was asked to inflate or deflate the ETT cuff to what they thought was the correct pressure based on palpation of the pilot balloon and the ETT cuff pressure was measured. In the PRT group, a 7 ml loss of resistance syringe was attached to the pilot balloon, the ETT cuff was briefly over inflated and then the plunger of the syringe was allowed to passively recoil. Once the plunger had stopped moving, pressure was recorded. No mention is made of how much air was initially instilled into the ETT cuff in order to achieve the brief period of over-inflation or if a new syringe was used for each patient. The results

showed 66.3% of patients in the PRT group had an ETT cuff pressure within the recommended range, which was significantly more than 22.5% in the PBP group. More ETT cuffs were found to be under-inflated in the PRT group, but it is not known if the difference is significant. In the PRT group, only one ETT cuff pressure was found to be above 40 cmH_2O compared to 43 in the PBP group (40).

In summary, the results of the studies that have looked at PRT are variable. Both technique and type of syringe used are not standardised and it is not possible to have a clear indication on whether this is a reliable technique or not. The majority of studies performed on patients and not tracheal models have shown positive results.

1.9 The physics of pressure in different sized syringes

It is not clear, from the discussed evidence, which syringe size and type would be ideal for the PRT. The physical principles of the syringes need to be considered to determine which syringe choice would be suitable.

The friction between the syringe plunger and barrel that needs to be overcome before the plunger begins to recoil is static friction. The friction between the plunger and the barrel that resists the movement of the plunger after it has begun recoiling is dynamic friction. Syringe plungers often have synthetic rubber at the tip of the plunger and are lubricated with silicone which reduces dynamic friction. The material the syringe is made from and the lubrication used will have an effect on the friction observed. Static friction also increases with time and therefore the pulling back and forth of the plunger, which has been seen in many of the studies mentioned is important to reduce this friction.

The size of the syringe used will have an impact on results. It is known that pressure equals force per unit area:

$$P = \frac{F}{A}$$

meaning the pressure required to overcome a force is indirectly proportional to the surface area over which the force is acting (22). The force that needs to be overcome for the syringe plunger to be moved backwards is the static friction

between the plunger and the barrel of the syringe. Therefore “the larger surface area of the plunger of larger syringes means less pressure is required to overcome the force resulting from dynamic friction” (44).

1.10 Summary

With the advent of endotracheal intubation, it became clear that a seal between the trachea and the tube is necessary to allow for positive pressure ventilation and to protect the lower airways. With the ETT cuff in use, the complications of high ETT cuff pressures became an issue that needed addressing, hence the development of the high-volume, low-pressure ETT cuffs. However, even with these ETT cuffs, it has been shown that it is possible to have ETT cuff pressures which exceed tracheal perfusion pressures and therefore result in tracheal damage. Furthermore, studies have shown that under-inflated ETT cuffs can have negative effects on the intubated patient. It is therefore essential to obtain ETT cuff pressures within the recommended range.

Various patient, anaesthetic and surgical factors have been shown to have an effect on ETT cuff pressures and therefore, in a study assessing ETT cuff pressure measurements, these factors should be excluded. In the absence of a manometer to directly measure ETT cuff pressure, many estimation techniques have been used in an attempt to obtain ETT cuff pressures within the recommended range. Studies looking at the accuracy of these estimation techniques largely show that they yield pressures outside of the recommended range. It is therefore crucial that a more accurate technique is developed for use in resource-limited settings where no manometer is available. The PRT has been described with variations in methodology as well as outcomes. More research using a method based on accurate physical principles and standardised conditions is required to assess the accuracy of this technique in obtaining ETT cuff pressures within the recommended range.

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Section 3: Draft article

Pressure relief technique to achieve endotracheal tube cuff pressures within the recommended range.

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Running title: Pressure relief technique to achieve endotracheal tube cuff pressures within the recommended range.

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Declarations of interest: none.

Highlights

- The pressure relief technique, used to inflate endotracheal tube cuffs, is performed by over-inflating the endotracheal tube cuff and allowing the plunger of the syringe to recoil until it stops moving.
- The pressure relief technique yielded a statistically significant number of endotracheal tube cuff pressures within the recommended range in this study and can be used in settings where a manometer is not available.
- The brand of endotracheal tube used in the pressure relief technique has a significant impact on the endotracheal tube cuff pressure.

Abstract

Study Objective

The complications of both high and low endotracheal tube (ETT) cuff pressure have been well documented. A number of ETT cuff pressure estimation techniques have been employed by practitioners in the absence of a manometer, particularly in resource-limited settings. These techniques have largely been shown to be unreliable. The pressure relief technique (PRT) has been described, with variations in the exact method. This study aims to determine if PRT can achieve ETT cuff pressures within the recommended range.

Design

A cross-sectional study was performed

Setting

The study took place in the theatre complex of Chris Hani Baragwanath Academic Hospital in Johannesburg, South Africa

Patients

Included in the study were 146 adult surgical patients undergoing general anaesthesia.

Interventions

The PRT, using a predetermined, standardised volume of air, was performed by over-inflating the ETT cuff and then allowing the plunger of the syringe to recoil until it stopped moving.

Measurements

ETT cuff pressure was measured with a manometer and recorded. The volume of air remaining in the ETT cuff was calculated and recorded.

Main Result

A statistically significant number, 93 (63.7%), of ETT cuff pressures fell within the recommended range. A minimum ETT cuff pressure of 12 cmH_2O and a maximum of 42 cmH2O was recorded. ETT brand had a significant impact on ETT cuff pressure ($p=0.001$). The volume of air remaining in the ETT cuff, after the PRT was performed, was significantly impacted by the brand ($p<0.0005$) and size ($p<0.0005$) of ETT.

Conclusions

While the manometer remains the gold standard in ensuring ETT cuff pressures within the recommended range, in the absence of a manometer, the PRT yields a statistically significant number of ETT cuff pressures within the recommended range.

Key words: Endotracheal tube cuff pressures, pressure relief technique, manometer

3.1 Introduction

Endotracheal intubation has been used in medical practice since 1543 when Vesalius used it to ventilate dogs with pneumothoraxes (1, 2). Sir William Macewen first used it to administer anaesthesia in the eighteenth century by administering chloroform through this route during dental surgery (3). Cuffs on endotracheal tubes (ETT) were introduced by Trendelenburg in 1869 to prevent blood from entering the lower airway during surgery (2). With the advent of cuffed ETTs came the complications of tracheomalacia and stenosis. In response to this, Geffin and Pontoppidan (4) developed high-volume, low-pressure ETT cuffs to achieve an airtight seal at lower pressures than previously required.

The complications of high ETT cuff pressures are now well documented such as sore throat, hoarse voice, blood-stained expectorant (5), oedema, ulceration and necrosis of the trachea, destruction of tracheal cartilage resulting in tracheomalacia and in severe cases, tracheal rupture and fistulae (5, 6). Complications of underinflated ETT cuffs, for example, aspiration pneumonia, have also been described (7). It is recommended that ETT cuff pressures be maintained at 20 – 30 cmH_2O (7, 8). A 2016 systematic review (9) has shown that the best method to determine ETT cuff pressure is using a manometer and none of the ETT cuff pressure estimation techniques reliably yielded acceptable pressures.

A novel method of ETT cuff pressure estimation has been described, with variations in the exact method and name. This method has been called the pressure relief valve technique (10), the passive release technique (11-13) and the air return method (14). For the purposes of this study, it will be called the pressure relief technique (PRT). In principle, when the ETT cuff is overinflated, it causes tracheal distention, which then exerts an “opposing force of resistance” (10) on the ETT cuff. When the pilot balloon valve is opened by attaching a syringe, this force is transmitted to the plunger of the syringe and pushes it back. Theoretically, “when the syringe plunger stops moving, the tracheal wall pressure is considered equal to the ETT cuff pressure, thus maintaining it at safe levels” (10). This relies on the physics principle of air moving down a pressure gradient.

Studies have looked at this technique with differing methodologies. Gravenstein and Burwick, (15) in 1988, showed that when a syringe was left attached to a pilot balloon for one minute after ETT cuff inflation, the ETT cuff pressures were significantly lower than when no syringe was attached. Other studies (12, 14, 16-18) have examined variations of this technique with differing results. It was not always clear how ETT cuffs were inflated prior to PRT being performed. Some studies mention over-inflation prior to PRT being performed (14, 16, 17), but over-inflation could be largely subjective if a specific pressure or volume is not specified. The steps taken in performing the technique vary between studies, with some being performed on patients (12, 14, 16-18) and others on tracheal models (15, 19) or mannequins (13).

A study performed in two Johannesburg hospitals, including Chris Hani Baragwanath Academic Hospital (CHBAH), where manometers were not readily available, showed that only 18,7% of patients had ETT cuff pressures within the recommended range when using subjective estimation techniques such as pilot balloon palpation, minimal occlusive volume and a predetermined volume of air (20). In settings where a manometer is not always available, it is important to investigate an objective, standardised technique that could accurately ensure ETT cuff pressures are within the recommended range. The aim of this study was to determine the success of PRT in achieving ETT cuff pressures within the recommended range, in adult surgical patients undergoing general anaesthesia at CHBAH.

3.2 Methods

Approval to conduct the study was obtained from the Human Research Ethics Committee (Medical) of the University of the Witwatersrand (number M190835) and the medical advisory committee at CHBAH. A cross-sectional study design was followed. The study was conducted at CHBAH, a hospital affiliated to the University of the Witwatersrand. CHBAH is a 2 888 bed central hospital and has 25 theatres. On average, 65 000 surgeries are done annually.

The study population consists of all adult (18 years and older) patients requiring a general anaesthetic with endotracheal intubation at CHBAH. In consultation with a biostatistician, a sample size of 138 participants was estimated to have a power of 80% with a 95% level of confidence and an alpha value of 5%. This study made use of convenience sampling. The inclusion criteria for this study were: patients requiring a general anaesthetic with neuromuscular blockade and endotracheal intubation who consent to take part in the study. The exclusion criteria in this study were: patients presenting for or with previous head and neck surgery, patients with laryngotracheal pathology, female patients requiring a size ETT other than 7.0 or 7.5, male patients requiring a size ETT other than 7.5 or 8.0 and patients who required more than two attempts at intubation.

A standard pre-determined volume of air for a given size ETT was used for the PRT. Prior to enrolling patients in the study, the cuffs of ETT sizes 7.0, 7.5 and 8.0 of 3 brands (Well Lead Medical, Hitecare and Jiangxi Yikang Medical Devices Group) were inflated to a pressure of 35 cmH_2O and the volume of air required to attain this pressure was recorded. These were the brands that were available at the time of performing the study. To ensure a standardised, reproducible and objective method of overinflating the ETT cuff as the first step of PRT, an average volume for each size of ETT was obtained and this was taken as the standard volume of air used when performing PRT:

- size 7.0 ETT – 12 ml
- size 7.5 ETT – 13 ml
- size 8.0 ETT – 16 ml.

For elective surgery, informed written consent was obtained the day before. In the case of emergency surgery, elective surgery where the patient was not available the day before or regional anaesthesia being converted to general anaesthesia, the patient was approached post-operatively. Once they were discharged from recovery and had a Ramsay score of 2 (21), informed, written consent was obtained.

On the day of surgery, a general anaesthetic was administered by the anaesthetist. The brand and size ETT was selected by the anaesthetist. Before intubation, a new 20 ml Isigidi luer slip syringe was prepared by pushing the plunger back and forth three times to reduce any stickiness between the plunger and the barrel of the syringe. The anaesthetist performed the endotracheal intubation and the author (TF) then inflated the ETT cuff with the predetermined volume of air, using the prepared 20 ml syringe. Thereafter, the plunger of the syringe was released, allowing it to recoil. When the plunger stopped moving, the volume of air remaining in the ETT cuff was calculated. The syringe was disconnected from the valve and a manometer (VBM Medizintechnik GmbH Universal cuff pressure gauge) was used to measure the resultant pressure inside the ETT cuff. In the interest of non-maleficence, if an ETT cuff pressure was outside the recommended range it was corrected immediately. An ETT cuff pressure of 20 – 30 cmH_2O was considered normal. The manometer was cleaned with a 70% alcohol solution between each patient. The patient's height was measured using a tape measure and body mass index (BMI) was calculated using the weight given by the anaesthetist.

A standardised data collection sheet was used to collect the following data: patient characteristics, details of endotracheal tube used, number of intubation attempts, volume of air returned to syringe after PRT to calculate volume of air remaining in the ETT cuff and ETT cuff pressure after PRT.

Data were analysed in consultation with a statistician. ETT cuff pressures post PRT were categorised into five categories: <15 cmH_2O, 15 – 19 cmH2O, 20 – 30 cmH_2O, 31 – 35 cmH_2O and >35 cmH_2O. These were reported as numbers and percentages, as were the variables (sex, BMI, size of ETT and brand of ETT). Age, BMI and volume of air remaining in the ETT cuff were reported as

continuous variables using a median and inter-quartile range or a mean and standard deviation. Multinominal logistic regression was applied to assess the effect ETT size, ETT brand, sex, age and had on ETT cuff pressure. To assess the effect ETT size and ETT brand had on the volume of air remaining in the ETT cuff, a Kruskal-Wallis test and a Welch test were used respectively. A Mann-Whitney U test was used to compare sizes of ETT tubes and a Games-Howell post-hoc test was used to compare brands. A p-value of 0.05 or less was considered statistically significant.

3.3 Results

A total of 150 patients were approached to participate in the study. Of the 150, 2 were excluded due to more than 2 intubation attempts, and 2 declined consent. The characteristics of the remaining 146 participants are shown in Table 1.

The characteristics of the ETTs used in the study are shown in Table 2.

The median (IQR) ETT cuff pressure recorded was 26.0 cmH_2O (22.0 – 30.8 cmH_2O) with a minimum ETT cuff pressure of 12.0 cmH_2O and a maximum of 42.0 cmH_2O. A statistically significant number of ETT cuff pressures fell within the recommended range, 93 (63.7%; 95% CI: 81.6 – 104.4; p=<0.005). The frequency of ETT cuff pressures per range is shown in Figure 1.

The ETT cuff pressure and the volume of air remaining in the ETT cuff, according to brand and size ETT are shown in Table 3. The difference between the brands and sizes of ETT for ETT cuff pressure and volume of air remaining in the ETT cuff are shown in Table 4. Univariate analysis shows that ETT brand had a statistically significant effect on cuff pressure (p=0.001). The difference was found in the frequency of high cuff pressures in Brand 2 compared to Brand 3. ETT size had a statistically significant impact on ETT cuff pressure (p=0.004). Specifically, a difference was found when comparing the frequency of ETT cuff pressures >30 cmH_2O in size 8.0 ETT compared to both size 7.0 and 7.5 ETT. An interaction effect between ETT brand and ETT size was tested for, in order to account for the bias of the unequal distribution of various size ETTs across the 3 brands. No interaction effect was found.

The volume of air remaining in the ETT cuffs differed significantly across the different ETT brands (p<0.0005) and the significance was found to lie between Brand 1 compared to Brand 2 and Brand 2 compared to Brand 3. The volume of air remaining in the ETT cuffs also differed significantly across ETT sizes (p<0.0005), with the volume increasing, as ETT size increases. This statistically significant difference is present across all 3 sizes of ETT.

The impact of the individual variables on achieving recommended ETT cuff pressures after PRT is shown in Table 5. None of these variables had a significant

impact. Multivariate analysis shows that the only variable that had a significant effect on ETT cuff pressure is brand of ETT ($p=0.001$).

3.4 Discussion

The number of ETT cuff pressures that fell within the recommended range in this study was 63.7% which was similar to other studies using variations of the PRT. Bulumba et al, (16) who used a loss of resistance syringe found that 66.3% of participants had acceptable ETT cuff pressures after PRT. Park et al (13), who used mannequins to perform the PRT on, found acceptable ETT cuff pressures in 65.5% of participants. Tsaousi et al (14) found acceptable ETT cuff pressures in 70% of participants, however, they used a range of 20 – 35 cmH_2O for acceptable ETT cuff pressures. All three of these studies had smaller sample sizes than this study. The ETT cuff pressures were categorised into 5 categories to show the number of out-of-range ETT cuff pressures which fell just outside of the recommended range as opposed to well outside of the recommended range. It is worth noting that 13% of cuff pressures were more than 5 cmH_2O outside of the recommended range.

Size 8.0 ETTs yielded higher ETT cuff pressures. One possible explanation is that because a higher standard volume of air was used to inflate the size 8.0 ETT cuff during the PRT, a higher volume of air needed to be returned to the syringe. Friction in the barrel of the syringe may have limited the amount of air that returned to the syringe. Further testing using a lower standard volume of air for a size 8.0 ETT or a loss of resistance syringe is recommended.

The volume of air required to maximally inflate the ETT cuffs could not be obtained from the manufacturers. However, based on the steps taken to determine the standard volumes of air for each cuff size, it can be assumed that a larger size ETT will require a larger volume of air to maximally inflate the ETT cuff. The results showing the statistically significant impact size of ETT has on the volume of air remaining in the ETT cuff is to then be expected. Brand also showed a statistically significant impact on the volume of air remaining in the ETT cuff, and in post-hoc analysis was found to be the only variable with a significant impact on ETT cuff pressure after PRT. This could be explained by differing physical properties of ETT cuffs, such as elastance, across different brands of ETT and is something that anaesthetists should be cognisant of.

The outcome of the PRT is not comparable to the gold standard of a manometer when ensuring recommended ETT cuff pressures. However, in the hospital in which the study took place, as shown by Gilliland et al (20), manometers are not being used as standard practice. ETT cuff pressures were shown to be as high as 120 cmH_2O, compared to a maximum of 42 cmH_2O in this study. Only 18.8% of participants had ETT cuff pressures within the recommended range in Gilliland et al's (20) study, compared to 63.7% in this study. PRT can therefore, be recommended as a safer alternative to current practice in a resource-limited setting.

There was not an equal distribution of brands and size ETTs, and within each size, there was an unequal distribution of brands. This limitation was bought about by the fact that ETT brand and size were not randomised but rather chosen by the anaesthetist. The selection would have been primarily influenced by what brand of ETT was available at the time.

Conclusion

While the manometer remains the gold standard in ensuring ETT cuff pressures within the recommended range, in the absence of a manometer, the PRT yields a statistically significant number of ETT cuff pressures within the recommended range.

Conflict of interest

The authors declare that we have no financial or personal relationships which may have inappropriately influenced us in writing this paper.

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3.5 Tables and figures

Table 1: Characteristics of participants

	Number	Percentage
Sex		
• Male	70	47.9
• Female	76	52.1
BMI		
• Underweight (<18.5)	11	7.5
• Normal (18.5 – 24.9)	86	58.9
• Overweight (25 – 29.9)	32	21.9
• Obese (>30)	17	11.6
	Median	**IQR**
BMI	23.5	21.9 – 27.2
	Mean	**SD**
Age	42.7	15.6

Table 2: Frequency of ETT sizes and brands

	Size 7.0 (n)	Size 7.5 (n)	Size 8.0 (n)	Total
Brand 1	3	19	2	**24**
Brand 2	5	38	34	**77**
Brand 3	41	3	1	**45**
Total	**49**	**60**	**37**	**146**

Table 3: ETT cuff pressures and volume of air remaining in ETT cuff according to brand and size of ETT

	ETT cuff pressure (cmH_2O)			Volume of air remaining in ETT cuff (ml)		
	Median	**IQR**	**p-value**	**Median**	**IQR**	**p-value**
ETT brand (n)			0.001			<0.0005
• Brand 1 (24)	27	24.0 – 30.0		7	5.8 – 8.0	
• Brand 2 (77)	28	26.0 – 34.0		8	6.0 – 10.0	
• Brand 3 (45)	24	22.0 – 26.0		6	5.0 – 7.0	
ETT size (n)			0.004			<0.0005
• 7.0 (49)	24	22.0 – 28.0		6	5.0 – 7.0	
• 7.5 (60)	26	22.0 – 30.5		7	5.4 – 8.0	
• 8.0 (37)	30	26.0 – 34.0		10	8.0 – 11.0	

Table 4: p-values for differences between brand and size ETT, for ETT cuff pressure and volume remaining in ETT cuff

	Pressure <20 cmH_2O p-value	Pressure >30 cmH_2O p-value	Volume remaining in ETT cuff p-value
ETT brand			
• Brand 1 and 2	0.907	0.078	**0.049**
• Brand 1 and 3	0.569	0.181	0.059
• Brand 2 and 3	0.834	**0.001**	**<0.0005**
ETT size			
• 7.0 and 7.5	0.349	0.79	**0.002**
• 7.0 and 8.0	0.755	**0.001**	**<0.0005**
• 7.5 and 8.0	0.661	**0.032**	**<0.0005**

Table 5: Sex, BMI and age impact on ETT cuff pressure after PRT

	ETT cuff Pressure (cmH_20)		p-value
	Median	**IQR**	
Sex			0.056
• Male	28	22.5 – 32.0	
• Female	26	22.0 – 29.0	
BMI			0.652
• Underweight	24	20.5 – 29.0	
• Normal	26	22.0 – 32.0	
• Overweight	26	22.0 – 30.0	
• Obese	26	26.0 – 34.0	
Age			0.880

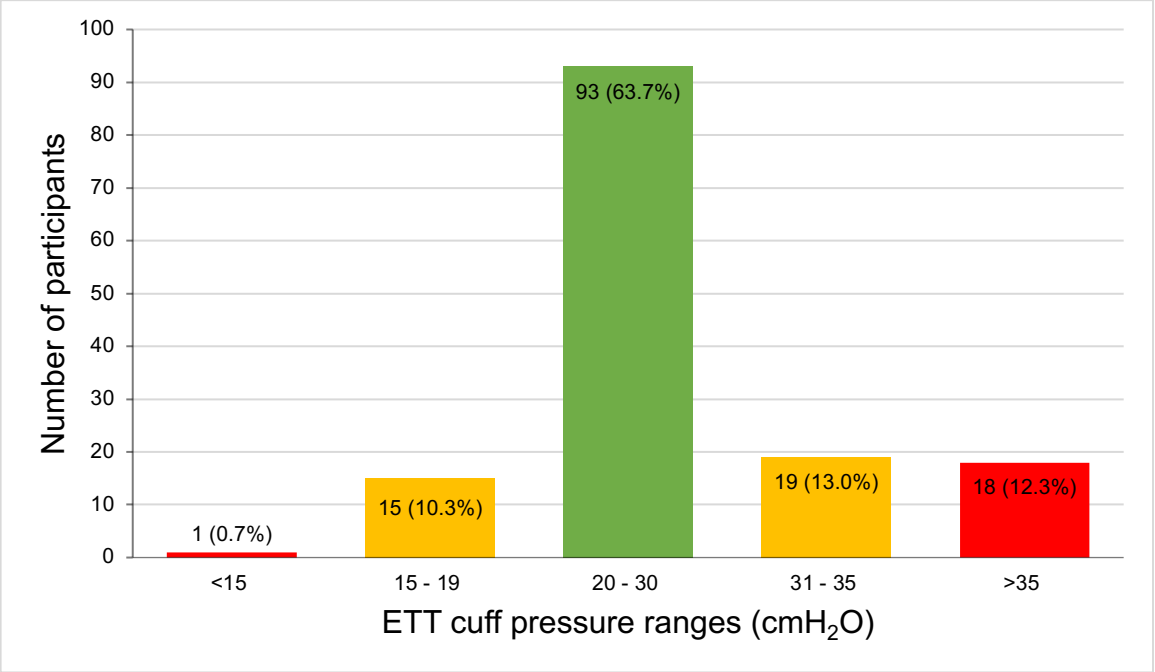


Figure 1: Frequency of ETT cuff pressures per range

Section 4: Proposal

Pressure relief technique to achieve endotracheal tube cuff pressures within the recommended range.

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4.1 Introduction and problem statement

Endotracheal intubation has been used in medical practice since 1543 when Vesalius used it to ventilate dogs with pneumothoraxes (1, 2). It has been used to administer anaesthesia since the eighteenth century when Sir William Macewen administered chloroform through this route during dental surgery (3). Cuffs on endotracheal tubes (ETT) were introduced by Trendelenburg in 1869 to prevent blood from entering the lower airway during surgery (2). With the advent of cuffed ETTs came the complications of tracheomalacia and stenosis. In response to this, Geffin and Pontoppidan (4) developed high volume, low pressure ETT cuffs to achieve an airtight seal at lower pressures than previously required.

The complications of high ETT cuff pressures are now well documented such as sore throat, hoarse voice, blood-stained expectorant (5), oedema, ulceration and necrosis of the trachea, destruction of tracheal cartilage resulting in tracheomalacia and in severe cases, tracheal rupture and fistulae (5, 6). Complications of underinflated ETT cuffs, for example, aspiration pneumonia, have also been described (7). It is recommended that ETT cuff pressures be maintained at 20 – 30 cmH_2O (7, 8). A 2016 systematic review (9) has shown that the best method to determine ETT cuff pressure is using a manometer. The review included at nine studies that assessed ETT cuff pressure estimation techniques which could be used in the absence of a manometer. Examples of these techniques are the pilot balloon palpation technique, fixed volume of air technique and the minimum leak technique. None of these techniques reliably yield acceptable pressures.

A novel method of ETT cuff pressure estimation has been described, with variations in the exact method and name. This method has been called the pressure relief valve technique (10), the passive release technique (11-13) and the air return method (14). For the purposes of this study, it will be called the pressure relief technique (PRT). The principle of this technique is when the ETT cuff is overinflated, it causes tracheal distention, which then exerts an “opposing force of resistance” (10) on the ETT cuff. When the pilot balloon valve is opened by attaching a syringe, this force is transmitted to the plunger of the syringe and pushes it back. Theoretically, “when the syringe plunger stops moving, the

tracheal wall pressure is considered equal to the ETT cuff pressure, thus maintaining it at safe levels" (10). This relies on the physics principle of air moving down a pressure gradient.

Various studies have looked at this technique with differing methodologies. Gravenstein and Burwick, in 1988, (15) showed that when a syringe was left attached to a pilot balloon for one minute after ETT cuff inflation, the ETT cuff pressures ranged between 19 – 74 cmH_2O, compared to 209 – 254 cmH_2O when no syringe was attached. In 1990, Resnikoff and Katz (16) attempted to improve on this by using a modified epidural syringe with resultant ETT cuff pressures falling between 13 – 22 cmH_2O. Similarly, in 2002, Somri et al (17) showed that when a syringe is left attached to the pilot balloon during anaesthesia with nitrous oxide, the ETT cuff pressures remained stable at 15.2 – 15.4 cmH_2O. In a study performed by Huh et al in 2009 (12), pressures between 12.5 – 30.4 cmH_2O were achieved using PRT. In 2017, Bulamba et al (18) showed a 66.3% success rate with PRT compared to 22.5% with pilot balloon palpation. When Tsaousi et al, in 2018, (14) compared PRT to three other methods of ETT cuff pressure estimation, it was found to give recommended pressures in 69.5% of patients. The minimum volume technique resulted in 44% of pressures falling within the recommended range, while the minimum leak technique resulted in 17% of pressures falling in the recommended range. The pilot balloon palpation technique resulted in 80% of pressures falling within the recommended range (14), however this technique has previously been found to be unreliable (19).

There is no clear, objective and standardised practice described for PRT. It is not always clear how ETT cuffs were inflated prior to PRT being performed. Some mention over-inflation prior to PRT being performed (14, 16, 18), but over-inflation could be largely subjective if a specific pressure or volume is not specified. The steps taken in performing the technique vary greatly between studies, with some being performed on tracheal models or mannequins (13, 16, 20).

A study performed in two Johannesburg hospitals, including Chris Hani Baragwanath Academic Hospital (CHBAH), where manometers were not readily available, showed that only 18,7% of patients had ETT cuff pressures within the recommended range when using subjective estimation techniques such as pilot

balloon palpation, minimal occlusive volume and a predetermined volume of air (21). In settings where a manometer is not always available, it is important to investigate an objective, standardised technique which could accurately ensure ETT cuff pressures are within the recommended range.

4.2 Aim and objectives

4.2.1 Aim

The aim of this study is to determine if PRT can achieve ETT cuff pressures within the recommended range in adult surgical patients undergoing general anaesthesia at CHBAH.

4.2.2 Objectives

The primary objectives of this study are to**:**

- determine the volume of air remaining in the ETT cuff following PRT
- determine pressures of ETT cuffs following PRT using a manometer.

The secondary objectives of this study are to:

- determine the impact of patient sex on achieving ETT cuff pressures within the recommended range
- determine the impact of patient age on achieving ETT cuff pressures within the recommended range
- determine the impact of body mass index (BMI) on achieving ETT cuff pressures within the recommended range
- determine the impact of ETT size on achieving ETT cuff pressures within the recommended range
- determine the impact of brand of ETT on achieving ETT cuff pressures within the recommended range.

4.3 Research assumptions

The following definitions will be used in this study:

Adult: is a person 18 years and older.

Recommended ETT cuff pressure range: is 20 – 30 cmH_2O (7, 8).

Predetermined volume of air: is the volume of air required to inflate the cuff of an ETT to 35 cmH_2O before being inserted into an airway.

Manometer: is a VBM Medizintechnik GmbH Universal cuff pressure gauge.

Syringe: is a 20 ml Isigidi luer slip syringe

Endotracheal tube: is one of the available brands at CHBAH at the time of the study. The number of brands used will be limited to three.

4.4 Demarcation of study field

The study will be conducted in the theatre complex of CHBAH affiliated to the Department of Anaesthesiology at the University of the Witwatersrand. CHBAH is a 2 888 bed central hospital. The hospital has 25 theatres. On average, 65 000 surgeries are done annually.

4.5 Ethical considerations

Approval to conduct the study will be obtained from the Human Research Ethics Committee (Medical) and the Graduate Studies Committee of the University of the Witwatersrand. Permission to conduct the study has been obtained from the Medical Advisory Committee at CHBAH (Appendix 1) and has been obtained from the Head of Department of Anaesthesiology at CHBAH (Appendix 2).

Where possible, elective surgery patients will be approached a day prior to their surgery**.** The study will be explained to them and they will be invited to take part. If they agree, they will be given an information letter (Appendix 3) and asked to sign a consent form (Appendix 4).

In the following circumstances, it will not be possible to obtain patient consent prior to surgery and deferred consent will be requested:

- emergency surgery

- anaesthetic converted from regional to general anaesthetic intra-operatively
- patient airway device converted from supra-glottic airway to ETT intra-operatively
- elective surgery patients who are not available the day prior to surgery.

Post operatively, once the patient has been discharged from recovery and has a Ramsay Score of 2 (22), the study will be explained to the patient and they will be invited to take part. If they agree, an information letter will be given to them (Appendix 5) and they will be asked to sign a consent form (Appendix 4). If they decline, their data will be excluded from the study. In the event that an eligible patient is not fit to give prior or deferred consent, a family member will be approached. The study will be explained to them and if they agree for their family member to be enrolled in the study, they will be given an information letter (Appendix 6) and asked to sign a consent form (Appendix 7). Once the patient is fit to provide consent, they will be made aware that their family member gave consent for them to be enrolled in the study. The study will be explained to them and they will be given a choice of whether they would like to participate in the study or not. If they agree to remain in the study, they will be given an information letter (Appendix 5) and asked to sign a consent form (Appendix 4). If they are not willing to remain a part of the study, their data will be excluded from the study.

The study will be explained to the anaesthetist administering the anaesthetic for the patient and verbal consent will be obtained to perform PRT on intubation.

To ensure anonymity, no identifying information will be collected and patients will be identified with a study number. A separate list with patient names, hospital numbers and study numbers will be kept. Only the researcher and supervisors will have access to raw data to ensure confidentiality.

In the interest of non-maleficence, if an ETT cuff pressure is above the recommended range after inflation, it will only be such for a maximum of 30 seconds. PRT will be performed immediately after inflation and the ETT cuff

pressure will then be measured with a manometer. If the pressure falls out of the recommended range, it will be corrected immediately.

Data will be stored securely for six years after completion of the study, electronically on a password-protected database. The study will be conducted according to the principles of the Declaration of Helsinki (23) and the South African Guidelines for Good Clinical Practice (24).

4.6 Research methodology

4.6.1 Research design

The research design outlines the plan for collecting study data (25). A cross-sectional research design will be followed in this study.

A cross-sectional study collects information at a single point in time (25). This study will be cross-sectional because it will be observing the effect that PRT has on ETT cuff pressure and the data will be collected at the time that the intervention is taking place.

4.6.2 Study population

The study population consists of all adult patients requiring a general anaesthetic with endotracheal intubation at CHBAH.

4.6.3 Study sample

Sample size

The sample size was calculated in consultation with a biostatistian. A sample size of 138 partcipants was estimated to have a power of 80% with a 95% level of confidence and an alpha value of 5%.

Sampling method

This study will make use of convenience sampling. Convenience sampling is when participants are included in the study because they are easily accessible (25). Adult patients undergoing a general anaesthetic at CHBAH during the study period will be invited to participate in the study.

Inclusion and exclusion criteria

The inclusion criteria for this study are adult patients requiring a general anaesthetic with neuromuscular blockade and endotracheal intubation who consent to take part in the study.

The exclusion criteria in this study are:

- patients with previous head and neck surgery
- patients presenting for head and neck surgery
- patients with laryngotracheal pathology
- female patients requiring a size ETT other than 7.0 or 7.5
- male patients requiring a size ETT other than 7.5 or 8.0
- patients who required more than two attempts at intubation.

4.6.4 Data collection

A standard volume of air for a given size ETT will be used for the PRT. Prior to enrolling patients in the study, ETT sizes 7.0, 7.5 and 8.0 of brands available at CHBAH at the time of the study will be collected. The number of brands used will be limited to three. The cuffs of the selected ETTs will be inflated to a pressure of 35 cmH_2O and the volume of air required to attain this pressure will be recorded for each ETT brand and size. An average volume for each size of ETT will be obtained and this will be taken as the standard volume of air used when performing PRT. This will ensure a standardised, reproducible and objective method of overinflating the ETT cuff as the first step of PRT.

In the case of elective surgery, the patient will be identified the day before surgery and if available, will be informed of the study details. If the patient agrees to participate, they will be provided with an information letter (Appendix 3) and asked to sign the consent form (Appendix 4).

On the day of surgery, the patient will be taken into theatre and a general anaesthetic will be administered by the anaesthetist. Before intubation, a new 20 ml syringe will be prepared by pushing the plunger back and forth three times to negate any stickiness between the plunger and the barrel of the syringe. A new

syringe will be used for each patient. The anaesthetist will insert the ETT into the airway and position it at a depth which they deem appropriate. The researcher will then inflate the ETT cuff with the predetermined volume of air, using the prepared 20 ml syringe. Once the predetermined volume of air has been instilled into the ETT cuff, the researcher will release the plunger of the syringe and allow it to recoil. When the plunger stops moving, the volume of air in the syringe will be recorded, and from this, the volume of air remaining in the ETT cuff will be calculated. The syringe will be disconnected from the valve and a manometer will be used to measure the resultant pressure inside the ETT cuff. This pressure will be documented. If the pressure is outside the recommended range, it will be corrected. The manometer will be cleaned with alcohol between each patient. The patient's height will be measured using a tape measure and BMI will be calculated using the weight given by the anaesthetist.

In the case of emergency surgery, elective surgery where the patient is not available the day before or regional anaesthesia being converted to general anaesthesia with placement of an ETT intra-operatively, they will be identified at the time of surgery and data will be collected as described. They will then be approached post-operatively, once they are discharged from recovery and have a Ramsay score of 2 (22), and informed of the study details. If they agree to participate, they will be given an information letter (Appendix 5) and asked to sign a consent form (Appendix 4). If the patient is unable to consent at that time, a family member will be informed of the study and asked to sign a consent form (Appendix 7) if they agree to their relative participating. The patient will then be followed up until they are able to give consent themselves. At that time, they will be informed of the study and their relative's consent. If they agree to remain a participant in the study, they will be asked to sign a consent form (Appendix 4).

Data collection sheet

A standardised data collection sheet will be used to collect data (Appendix 8). It will collect the following data:

- patient characteristics
- details of the ETT used

- number of intubation attempts
- volume of air returned to syringe after PRT
- ETT cuff pressure after PRT.

4.6.5 Data analysis

A Microsoft Excel spreadsheet will be used to capture data. Data will be analysed in consultation with a statistician.

Volume of air remaining in the ETT cuff will be reported as a mean with a standard deviation or a median with an inter-quartile range depending on if it is normally distributed or not.

ETT cuff pressures post PRT will be categorised and reported as numbers and percentages, as will the variables (sex, BMI, size of ETT and brand of ETT). Age will be reported as a continuous variable.

To evaluate the effect the variables have on the sensitivity of PRT, univariable regression of each factor against the outcome will be done. Multivariable analysis using step-wise forward regression will be conducted. A p-value of 0.05 or less will be considered statistically significant.

4.7 Significance of the study

Although the gold standard for ETT cuff pressure monitoring is an objective measurement with a manometer, this tool is not readily available in resource-limited settings (18). The complications of ETT cuff pressures outside of the recommended range are widely documented (5-8) and it is therefore important that despite a lack of resources, a cost-effective and reliable way of ETT cuff pressure estimation is developed. The methods currently in use have been shown to be inaccurate (21). A 20 ml syringe should be widely available and this is the only tool needed for PRT. Should this technique prove to be reliable in obtaining ETT cuff pressures within the recommended range, it would allow for safer intubations in resource-limited settings.

4.8 Validity and reliability of the study

Validity refers to whether the results of a study are due to a hypothesised cause or have occurred due to outside circumstances. Reliability of a study refers to the reproducibility of results when the method is used in different circumstances (26). A number of factors have been considered to ensure the validity and reliability of this study:

- the research design is appropriate for the aim of the study
- the sample size was determined in consultation with a biostatistician
- data collection will only be performed by the researcher and one supervisor
- data collection procedure is standardised and the researcher and supervisor collecting data will practice the technique together
- one manometer will be used to measure ETT cuff pressure
- syringe size and brand will be standardised
- data will be analysed together with a statistician.

4.9 Potential limitations

The results should only be applied to patients who have received a neuromuscular blocker. Intubated patients without neuromuscular blockade still require ETT cuff pressure measurement, however, this study does not investigate PRT in this subgroup. The study was done contextually and therefore results may not be generalisable to other populations.

4.10 Project outline

4.10.1 Time frame

Activity	Aug 2019	Sep 2019	Oct 2019	Nov 2019	Dec 2019	Jan 2020	Feb 2020	Mar 2020	Apr 2020	May 2020
Proposal preparation										
Literature review										
Proposal submission										
Ethics approval										
Postgraduate approval										
Data collection										
Data analysis										
Draft article										
Submission										

4.10.2 Budget

Item	Price per page/unit	Number of pages/units	Copies	Total
Proposal	R1,00	25	6	R150,00
Postgraduate application	R1,00	2	6	R12,00
Complete report	R1,00	100	4	R400,00
Syringes	R4,70	154		R723,80
Manometer	R2012,5	1		R2012,50
Grand Total				**R3298,30**

The Wits Department of Anaesthesiology will incur the costs of paper and printing of the postgraduate application. The supply of syringes to CHBAH is unreliable. The researcher will therefore have her own stock of 20 ml syringes to use in the study, which will be incurred as a personal expense, as will the manometer. The

patients would have been intubated with ETTs from the hospital supply, regardless of whether they were going to participate in the study or not, therefore, this will not incur an extra expense to the hospital.

4.11 References

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4.12 Appendices

Appendix 1: Medical Advisory Committee permission

GAUTENG PROVINCE
HEALTH
REPUBLIC OF SOUTH AFRICA

MEDICAL ADVISORY COMMITTEE

CHRIS HANI BARAGWANATH ACADEMIC HOSPITAL

PERMISSION TO CONDUCT RESEARCH

Date: 8th October 2019

TITLE OF PROJECT:

Reliability of the pressure relief technique to achieve tube cuff pressures within the recommended range.

UNIVERSITY: Witswatersrand

Principal Investigator: Dr Tracey Ferreira

Department: Anaesthesiology

Supervisor : Helen Perrie

Permission Head Department (where research conducted): Yes

The Medical Advisory Committee recommends that the said research be conducted at Chris Hani Baragwanath Academic Hospital. The CEO / management of Chris Hani Baragwanath Academic Hospital is accordingly informed and the study is subject to:-

- **Permission having been granted by the Committee for Research on Human Subjects of the University of the Witwatersrand.**
- The Hospital will not incur extra costs as a result of the research being conducted on its patients within the hospital
- The MAC will be informed of any serious adverse events as soon as they occur
- Permission is granted for the duration of the Ethics Committee Approval.

Recommended
(On behalf of the MAC)
Date: 8/10/2019

Approved/Not Approved
Hospital Management
Date: 09/10/2019

Appendix 2: Request to Head of Department



Appendix 2: Request to Head of Department

Dear Dr Lines

I am a registrar in the Department of Anaesthesiology. I am conducting research as part of my Masters of Medicine in Anaesthesiology. The title of my study is: Reliability of the pressure relief technique to achieve endotracheal tube cuff pressures within the recommended range.

The study will include adult patients presenting for surgery who require a general anaesthetic with endotracheal intubation. I will be testing a novel technique to ensure that endotracheal tube cuff pressure is within the recommended range which could be used when a manometer is not available. The technique involves inflating the cuff with a predetermined volume of air and then releasing the plunger of the syringe and allowing it to recoil until the pressure has equalised. The pressure will then be measured with a manometer and corrected if it falls outside of the reference range. All of the patient care will be routine and there is no risk of harm to the patient. No extra cost will be incurred to the hospital as I will supply syringes and the endotracheal tubes will come from the supply that would normally be used for the patient

The study has been approved by the Human Research Ethics Committee (Medical) (number xxx) and the Graduate Studies Committee of the University of the Witwatersrand.

I am requesting permission to conduct my research at CHBAH from November 2019 until the target number of participants is reached.

Yours sincerely,

Dr Tracey Ferreira
0823520272
traceyjferreira@gmail.com

Permission granted

06/08/2019

Dr. D. LINES

Appendix 3: Patient information letter for patients prior to surgery

Hello, my name is Tracey Ferreira and I am a doctor who is training to become an anaesthesiologist (a doctor who makes people sleep during surgery). I am training through the University of the Witwatersrand. I am doing research and would like to invite you to participate.

When a patient is put to sleep for surgery a tube is placed in their windpipe to help them to breathe. There is a balloon around the tube, which is blown up once the tube is in the windpipe. This is to make sure no liquids can enter the lungs while the patient is sleeping. It is important that the pressure inside the cuff is not too high, so it does not damage the windpipe. I am researching a method of making sure the pressure is not too high, by using a syringe to allow extra air to escape. After doing this, I will measure the pressure in the cuff. If the reading is too high or too low, I will correct it.

You may benefit from participating in this study because I will make sure that the pressure inside the cuff is correct. You will also be helping us to see if this technique can be used to help other patients in the future.

It is your choice to participate in the study or not. If you do not want to participate, the care you receive at the hospital will not change. At any time you can change your mind and withdraw from the study. If you do not want to participate I will not use the information I got from you.

The information I collect will have a number on it, and not your name, so that no one will be able to identify you from the information. All information will be kept secret and will only be seen by the people doing the research. The information will be kept on a computer with a password that only the researchers will have.

This study has been approved by the Human Research Ethics Committee (HREC) (number M190835), which makes sure that participants in research are not harmed, and the Graduate Studies Committee of the University of the Witwatersrand. If you would like to contact them their details are: Professor Penny (Chairperson HREC): 011 717 2301 or clement.penny@wits.ac.za, Committee secretariat: 011 717 2700/1234 or Zanele.Ndlovu@wits.ac.za or Rhulani.Mkansi@wits.ac.za.

If you have any questions you may ask me. You can contact me on 011 933 9564.

Thank you for your time.

Appendix 4: Consent to participate in study

The study has been explained to me and I understand the information given to me. An information sheet has been given to me. I have been given the opportunity to ask questions and my questions have been answered. I understand that my information will be kept secret. I give consent to participate in this study.

Print patient name _____

Patient signature _____

Date _____

I have witnessed the counseling of this patient with regards to the study. I confirm that the patient was given the opportunity to ask questions. I confirm that consent was provided freely.

Print witness name _____

Witness signature _____

Date _____

Appendix 5: Patient information sheet for deferred consent

Hello, My name is Tracey Ferreira and I am a doctor who is training to become an anaesthesiologist (a doctor who makes people sleep during surgery). I am training through the University of Witwatersrand. I am doing research and would like to invite you to participate.

When a patient is put to sleep for surgery a tube is placed in their windpipe to help them to breathe. There is a balloon around the tube, which is blown up once the tube is in the windpipe. This is to make sure no liquids can enter the lungs while the patient is sleeping. It is important that the pressure inside the cuff is not too high, so it does not damage the windpipe. I am researching a method of making sure the pressure is not too high, by using a syringe to allow extra air to escape. When you were put to sleep for your operation, I performed this technique and then I measured the pressure in the cuff. If the reading was too high or too low, I corrected it.

You may have benefitted from this study because I made sure that the pressure inside the cuff is correct. If you agree to participate you will also be helping us to see if this technique can be used to help other patients in the future.

It is your choice to participate in the study or not. If you do not want to participate, the care you receive at the hospital will not change. At any time, you can change your mind and withdraw from the study. You can decide if the information I have collected will be used in the study or not. If you do not want to participate the information will not be used.

The information I collect will have a number on it, and not your name, so that no one will be able to identify you from the information. All information will be kept secret and will only be seen by the people doing the research. The information will be kept on a computer with a password that only the researchers will have.

This study has been approved by the Human Research Ethics Committee (HREC) (number M190835), which makes sure that participants in research are not harmed, and the Graduate Studies Committee of the University of the Witwatersrand. If you would like to contact them their details are: Professor Penny (Chairperson HREC): 011 717 2301 or clement.penny@wits.ac.za, Committee secretariat: 011 717 2700/1234 or Zanele.Ndlovu@wits.ac.za or Rhulani.Mkansi@wits.ac.za.

If you have any questions you may ask me. You can contact me on 011 933 9564.

Thank you for your time.

Appendix 6: Information letter for patient's family

Hello, My name is Tracey Ferreira and I am a doctor who is training to become an anaesthesiologist (a doctor who makes people sleep during surgery). I am training through the University of Witwatersrand. I am doing research and would like to invite your family member to participate.

When a patient is put to sleep for surgery a tube is placed in their windpipe to help them to breathe. There is a balloon around the tube, which is blown up once the tube is in the windpipe. This is to make sure no liquids can enter the lungs while the patient is sleeping. It is important that the pressure inside the cuff is not too high, so it does not damage the windpipe. I am researching a method of making sure the pressure is not too high, by using a syringe to allow extra air to escape. When your family member was put to sleep for their operation, I performed this technique and then I measured the pressure in the cuff. If the reading was too high or too low, I corrected it.

Your family member may have benefitted from this study because I made sure that the pressure inside the cuff is correct. If you agree to allow your family member to participate you will also be helping us to see if this technique can be used to help other patients in the future.

It is your choice to have your family member participate in the study or not. If you do not want them to participate, the care they receive at the hospital will not change. At any time, you can change your mind and withdraw your family member from the study. You can decide if the information I have collected will be used in the study or not. If you do not want your family member to participate the information will not be used. I will also ask your family member themselves once they are able to give permission.

The information I collect will have a number on it, and not your family member's name, so that no one will be able to identify them from the information. All information will be kept secret and will only be seen by the people doing the research. The information will be kept on a computer with a password that only the researchers will have.

This study has been approved by the Human Research Ethics Committee (HREC) (number M190835), which makes sure that participants in research are not harmed, and the Graduate Studies Committee of the University of the Witwatersrand. If you would like to contact them their details are: Professor Penny (Chairperson HREC): 011 717 2301 or clement.penny@wits.ac.za, Committee secretariat: 011 717 2700/1234 or Zanele.Ndlovu@wits.ac.za or Rhulani.Mkansi@wits.ac.za.

If you have any questions you may ask me. You can contact me on 011 933 9564.

Thank you for your time.

Appendix 7: Consent form for family member

The study has been explained to me and I understand the information given to me. An information sheet has been given to me. I have been given the opportunity to ask questions and my questions have been answered. I understand that my family members information will be kept secret. I give consent for my family member _____(name of participant) to participate in this study.

Print family member name _____

Family member signature _____

Date _____

I have witnessed the counselling of this family member with regards to the study. I confirm that the family member was given the opportunity to ask questions. I confirm that consent was provided freely.

Print witness name _____

Witness signature _____

Date _____

Appendix 8: Data collection sheet

1. Patient number

2. Demographics

2.1	Patient age		
2.2	Patient sex	Male	Female
2.3	Patient height		m
2.4	Patient weight		kg
2.5	Patient BMI ($\frac{weight}{height^2}$)		

3. Endotracheal intubation details

3.1	Brand of endotracheal tube used			
3.2	Size of endotracheal tube used	7.0	7.5	8.0
3.3	Number of attempts at intubation	1	2	>2
3.4	Volume of air returned to syringe after PRT			ml
3.5	ETT cuff pressure after PRT			cmH_2O

Section 5: Annexures

5.1 Notification of change of title

UNIVERSITY OF THE WITWATERSRAND, JOHANNESBURG | FACULTY OF HEALTH SCIENCES

09 Oct, 2020.

Change of title: Dr T Ferreira, student number 300657

The title of this research report was changed following assessment of the proposal at the Postgraduate Assessors meeting. The title was subsequently changed again to reflect more accurately what was done. The appropriate authorities have been notified and have approved the title: **Pressure relief technique to achieve endotracheal tube cuff pressures within the recommended range**. This title may, however, not be reflected in all the documentation in this report.

Yours sincerely,

H Perrie

Helen Perrie
Supervisor

5.2 Ethics approval

UNIVERSITY OF THE WITWATERSRAND, JOHANNESBURG

R14/49 Tracey Ferreira

HUMAN RESEARCH ETHICS COMMITTEE (MEDICAL)

CLEARANCE CERTIFICATE NO. M190835 MED19-08-048

NAME: (Principal Investigator)	Tracey Ferreira
DEPARTMENT:	Anaesthesiology Chris Hani Baragwanath Academic Hospital
PROJECT TITLE:	Sensitivity of the pressure relief technique to achieve endotracheal tube cuff pressures within the recommended range
DATE CONSIDERED:	30/08/2019
DECISION:	Approved unconditionally
CONDITIONS:	
SUPERVISOR:	Helen Perrie, Juan Scribante and Chistopher Anamourlis
APPROVED BY:	Dr C Penny, Chairperson, HREC (Medical)
DATE OF APPROVAL:	08/11/2019

This clearance certificate is valid for 5 years from date of approval. Extension may be applied for.

DECLARATION OF INVESTIGATORS

To be completed in duplicate and **ONE COPY** returned to the Research Office Secretary in Room 301, Third floor, Faculty of Health Sciences, Phillip Tobias Building, 29 Princess of Wales Terrace, Parktown, 2193, University of the Witwatersrand. I/we fully understand the conditions under which I am/we are authorized to carry out the above-mentioned research and I/we undertake to ensure compliance with these conditions. Should any departure be contemplated, from the research protocol as approved, I/we undertake to resubmit the application to the Committee. **I agree to submit a yearly progress report**. The date for annual re-certification will be one year after the date of convened meeting where the study was initially reviewed. In this case, the study was initially reviewed August and will therefore be due in the month of August each year. Unreported changes to the application may invalidate the clearance given by the HREC (Medical).

Principal Investigator Signature

13/11/2019
Date

PLEASE QUOTE THE PROTOCOL NUMBER IN ALL ENQUIRIES

5.3 Graduate Studies Approval

UNIVERSITY OF THE
WITWATERSRAND,
JOHANNESBURG

Private Bag 3 Wits, 2050
Fax: 027117172119
Tel: 02711 7172076

Reference: Mrs Sandra Benn
E-mail: sandra.benn@wits.ac.za

29 October 2019
Person No: 300657
PAG

Dr TJ Ferreira
24 Elmwood
1 Juniper Drive
Dowerglen Ext 4
Edenvale
1609
South Africa

Dear Dr Tracey Ferreira

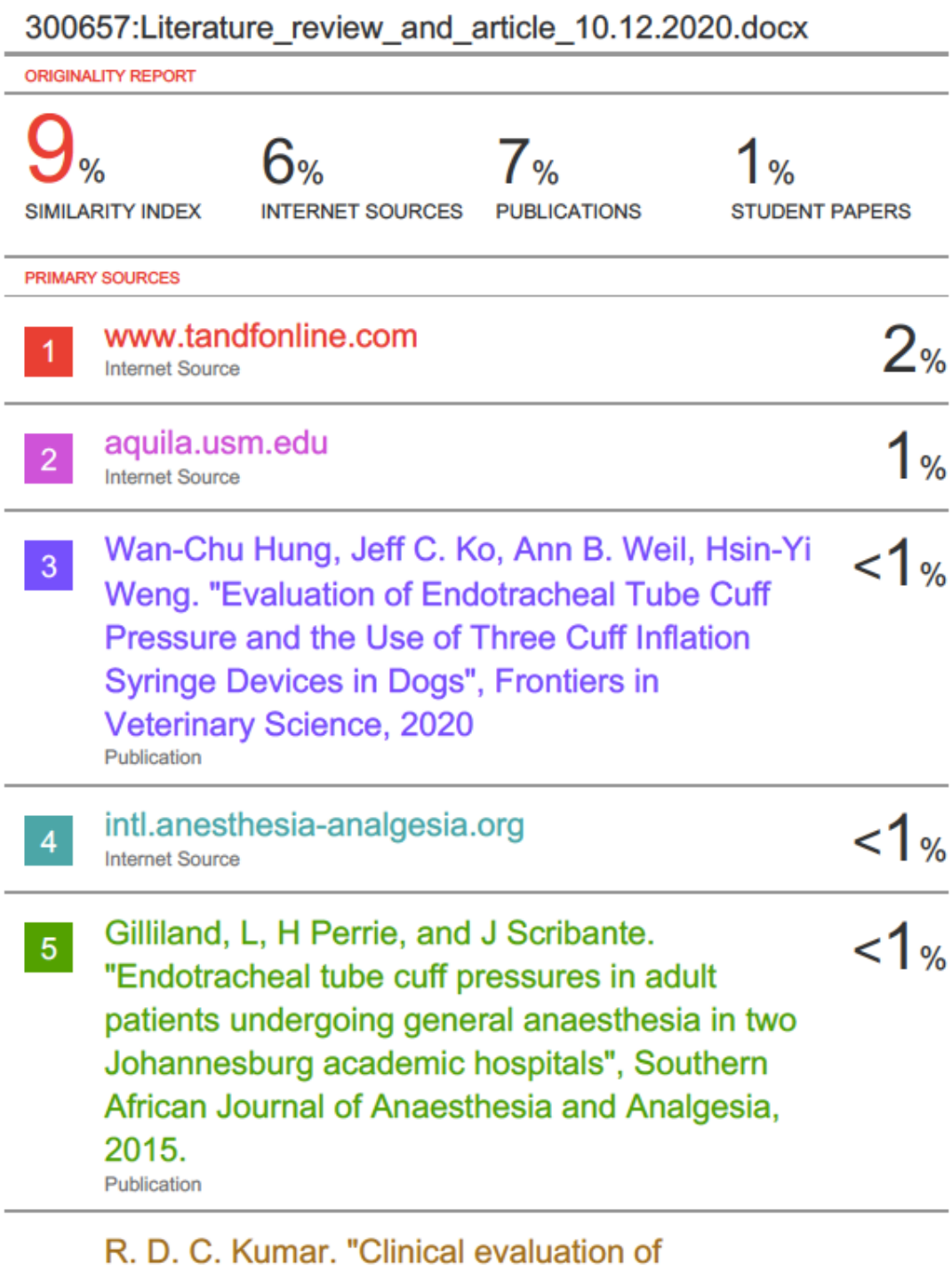
Master of Medicine in Anaesthesia: Approval of Title

We have pleasure in advising that your proposal entitled *Reliability of the pressure relief technique to achieve endotracheal tube cuff pressures within the recommended range*. has been approved. Please note that any amendments to this title have to be endorsed by the Faculty's higher degrees committee and formally approved.

Yours sincerely

Mrs Sandra Benn
Faculty Registrar
Faculty of Health Sciences

5.4 Turnitin report



300657:Literature_review_and_article_10.12.2020.docx

ORIGINALITY REPORT

9%	6%	7%	1%
SIMILARITY INDEX	INTERNET SOURCES	PUBLICATIONS	STUDENT PAPERS

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1	www.tandfonline.com Internet Source	2%
2	aquila.usm.edu Internet Source	1%
3	Wan-Chu Hung, Jeff C. Ko, Ann B. Weil, Hsin-Yi Weng. "Evaluation of Endotracheal Tube Cuff Pressure and the Use of Three Cuff Inflation Syringe Devices in Dogs", Frontiers in Veterinary Science, 2020 Publication	<1%
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